

## Cellular Reservoir Flexible Pressure Vessel, Apparatus and Method for Making Same

### Earlier Filed Application

The instant application is a continuation-in-part of applicant's prior application filed  
5 November 13, 2002 and having serial number 10/294,825 and currently pending, the  
disclosure of which is specifically incorporated by reference herein.

### Field of Invention

The invention pertains to devices for storing gases and fluids under pressure. More  
10 particularly, the invention relates to pressure vessels that are formed out of flexible materials  
and that can be made to conform to a variety of shapes.

### Background of the Invention

Typically, pressure vessels capable of containing liquids or gases at significant  
15 pressures have involved fixed shape cylinders or spheres formed of high-strength metals such  
as steel or aluminum. Such pressure vessels, while successful for their designed applications,  
involve a number of problems. First, such metallic cylinders are relatively heavy compared to  
the gases or fluids that they contain. Second, pressure cylinders contain all of the gas or liquid  
in a single space. Should the vessel rupture, the entire vessel is destroyed, often with a violent  
20 explosion sending shards of metal in all directions. Third, metallic cylinders have a definite  
shape and cannot be adapted to fit readily in many space-constrained applications. The  
present invention involves a number of small cells of an elongated tubular shape linked to

each other by collecting end caps. The result of this design is that the pressure vessel may be readily formed into a variety of useful shapes to accommodate special applications. A pressure vessel of this type can be lightweight, adaptable to a variety of spaces and unusual applications, and is inherently safer in rupture situations.

5           A particular problem associated with pressure vessels operated at high pressure is the conditions under which they fail. Metallic cylinders are particularly dangerous in this regard as they may fragment suddenly if aged or fatigued from many use cycles, even if equipped with overpressure release devices. The present invention provides for a number of controlled pressure release mechanisms that are easily incorporated into the flexible pressure vessels.

10           The use of numerous small linked pressure vessels also present problems related to effectively joining such vessels together. The present invention provides for novel manufacturing methods for joining such cells.

          Various designs have been developed using elongated tubular shaped vessels, most in the area of radiators and heat exchangers. U.S. Patent No. 6,390,187 issued to *Marechal et al.*  
15       discloses a heat exchanger with flexible tubes. The tubes may be made from a plastic material and are designed to carry a heat-exchanging fluid capable of cooperating with an air stream circulating through the exchanger. The invention is intended to describe the method by which the tubes are maintained in parallel rows. The tubes are made from a plastic material and communicate by way of their extremities with two manifolds. The manifolds include collector  
20       plates equipped with apertures that thus form a means for holding the tubes in place. The tubes are arranged in rows that are parallel to one another by a distance corresponding to the tube thickness so that the various rows are adjacent in pairs of respective tubes of two consecutive

pairs. The tubes generally exhibit a sinusoidal shape and thus aligned for expanding and contraction so that the tubes may utilize the flexible characteristics and maintain the integrity of the system.

U.S. Patent No. 4,450,902 issued to *Bosne*, is directed to a heat exchanger in particular  
5 for an atmospheric cooling tower. The exchanger utilizes synthetic plastic material for the tubes that has one fixed header while the remainder of the exchanger is mounted by suspension to allow for free expansion. A chamber has a heat exchanger with a series of tubes extending throughout the length of chamber. The exchanger comprises a battery of smooth tubes made of a synthetic material. The tubes of the heat exchanger are fixed to the support  
10 structure at one of the ends and is freely suspended by a suspension members to allow for expansion and contraction.

U.S. Patent No. 5,158,134, issued to *Mongia et al.*, discloses a fully floating tube bundle. The exchanger comprises a plurality of fluid carrying tubes that is free floating with no direct contact between the end plates or center plate. Thus, the tubes are free to move with  
15 respect to the end plates and center plate as to eliminate damage by vibration and temperature changes.

U.S. Patent No. 4,114,683 issued to *Verlinden* describes a flexible tube type fluid-fluid heat exchanger. The exchanger comprises a plurality of flexible synthetic tubes extending in a curved path between a pair of headers. The tubes are connected to headers and are  
20 constructed of a flexible plastic material so they may easily conform to the curvature of the wall 11.

U.S. Patent No. 5,651,474 issued to *Callaghan et al* is directed to cryogenic structures that are vessels made of a durable plastic material and are adapted to contain cryogenic materials such as fuel. The structures are made of a fiber network impregnated with a matrix of thermal set plastics and have three tank lobes of a composite plastic reinforced with fibers. The tank lobes may be filament-wound on a rotating mandrel while the fibers are pre-impregnated with resin. Another technique is to heat the tank skins allowing the pre-impregnated fiber layers to fuse together and then cool so as to set up a solid matrix that grips the fibers.

While other variations exist, the above-described designs involving elongated tubular shaped vessels are typical of those encountered in the prior art. It is an objective of the present invention to provide a flexible pressure vessel that is capable of maintaining gasses or liquids at relatively high pressures. It is a further objective to provide this capability in a vessel that is light in weight and that presents a significantly reduced risk of injury in rupture situations. It is a still further objective of the invention to provide a pressure vessel that may be easily adapted to a variety of space constraints. It is yet a further objective to provide a pressure vessel that is durable, easily serviced, and that may be produced inexpensively.

While some of the objectives of the present invention are disclosed in the prior art, none of the inventions found include all of the requirements identified.

#### Summary of the Invention

(1) A cellular reservoir flexible pressure vessel providing the desired features may be constructed from the following components. A plurality of flexible tubes is provided. Each of

the flexible tubes are formed of resilient material and have an outer surface, an inner surface, a first end and a second end.

First and second end caps are provided. Each of the end caps have a receptacle for either of the first or second ends of each of the flexible tubes, a collecting reservoir, a  
5 surrounding outer rim and an outer perimeter perpendicular to the surrounding outer rim. At least one of the first and second end caps have a passageway connecting to the collecting reservoir for connection to either a passageway of another pressure vessel or a valve. Each of the receptacles has a surrounding wall, a base and an orifice penetrating the base and connects the receptacle to either the collecting reservoir or the passageway. The wall has an interior  
10 surface. The interior surface is sized and shaped to fit frictionally over the outer surface of one of the flexible tubes at either the first or second ends. The collecting reservoir has an outer surface and connects the base of each of the receptacles to a common space. The common space is either closed or connected to the passageway. The surrounding outer rim extends outwardly from the outer surface of the collecting reservoir for a first predetermined  
15 distance along the flexible tubes and serves to constrain the flexible tubes.

Means are provided for securing the first and second end caps to the flexible tubes. A valving means is provided. The valving means is capable of controlling a flow of either a liquid or a gas through the passageway and is attached to a distal end of the passageway. When the flexible tubes are inserted into the receptacles of the end caps and secured thereto, a  
20 flexible pressure vessel will be formed capable of containing either a liquid or a gas at high pressure.

(2) In a variant of the invention, the means for securing the first and second end caps to the flexible tubes is selected from the group comprising: radio frequency welding, high-strength adhesive, mechanical fastening and sonic welding.

(3) In another variant of the invention, a protruding rim is provided. The protruding rim is located at the outer perimeter of the first and second end caps and upper and lower receiving notches located above and below the protruding rim. A reinforcing ring is provided. The reinforcing ring has an inner surface, an outer surface and is formed of high-strength material and is sized and shaped to fit tightly about the outer perimeter of the end cap. The reinforcing ring has an upper and lower projecting ribs and a central receiving notch located between the upper and lower projecting ribs. The projecting ribs are sized, shaped and located to fit the upper and lower receiving notches of the end cap. The central receiving notch is sized, shaped and located to fit the protruding rim of the end cap. The reinforcing ring has an aperture. The aperture extends from the inner surface to the outer surface and is sized, shaped and located to accommodate the passageway of the end cap. When the reinforcing ring is located about the outer perimeter of the first and second end caps, the pressure handling capacity of the pressure vessel is increased.

(4) In yet a further variant of the invention, a protruding rim is provided. The protruding rim is located at the outer perimeter of the first and second end caps and upper and lower receiving notches located above and below the protruding rim.

Upper and lower reinforcing rings are provided. Each of the reinforcing rings have an inner surface, an outer surface and are formed of high-strength material and are sized and shaped to fit tightly in either of the upper and lower receiving notches. At least one of the

reinforcing rings has an aperture. The aperture extends from the inner surface to the outer surface and is sized, shaped and located to accommodate the passageway connecting to the collecting reservoir. When the reinforcing rings are located about the outer perimeter of the first and second end caps, the pressure handling capacity of the pressure vessel is increased.

5           (5) In still a further variant, means are provided for fastening the upper reinforcing ring to the lower reinforcing ring.

          (6) In still a further variant of the invention, a protruding rim is provided. The protruding rim is located at the outer perimeter of the first and second end caps. At least one groove located about the outer perimeter above the protruding rim is provided. At least one  
10   groove located about the outer perimeter below the protruding rim is provided. Upper and lower reinforcing rings are provided. Each of the reinforcing rings have an inner surface, an outer surface and are formed of high-strength material and are sized and shaped to fit tightly about the outer perimeter on either side of the protruding rim. The reinforcing rings have at least one rib located upon the inner surface thereof, the rib is sized, shaped and located to  
15   engage the groove. When the reinforcing rings are located about the outer perimeter of the first and second end caps, the pressure handling capacity of the pressure vessel is increased.

          (7) In another variant, means are provided for fastening the upper reinforcing ring to the lower reinforcing ring.

          (8) In yet a further variant of the invention, a syntactic foam filler is provided. The  
20   foam filler is located within the collecting reservoir of at least one of the first and second end caps. The foam filler has a series of canals through it. Each of the canals connects the orifice of the receptacle to the passageway. An opening in the end cap is provided. The opening

provides means for introduction of the syntactic foam into the end cap. A sealing plug is provided. The sealing plug is sized and shaped to fit sealably into the opening in the end cap. When the syntactic foam is introduced into the end cap, the pressure handling capacity of the pressure vessel is increased.

5           (9) In still a further variant of the invention, a syntactic foam filler is provided. The foam filler is located within the collecting reservoir of at least one of the first and second end caps. The foam filler is penetrated by a series of flexible microtubes. Each of the microtubes connects the orifice of the receptacle to the passageway. An opening in the end cap is provided. The opening provides means for introduction of the syntactic foam into the end cap.

10   A sealing plug is provided. The sealing plug is sized and shaped to fit sealably into the opening in the end cap. When the microtubes are connected to the orifice of the receptacles in the end cap, the purity of either liquids or gasses stored in the pressure vessel is increased.

          (10) In yet a further variant of the invention, an overwrapping of high-strength braiding material is provided. The braiding material extends over the flexible tubes and the

15   first and second end caps. When the flexible pressure vessel is so overwrapped, its pressure-handling capability will be increased.

          (11) In still a further variant, hoop winding of the vessel with high-strength materials is provided. The hoop winding extends over the flexible tubes and the first and second end caps. When the flexible pressure vessel is so hoop wound, its pressure-handling capability will be

20   increased.

          (12, 13) In another variant, a plastic overcoating is provided. The overcoating further increases the pressure-handling capability of the pressure vessel.



(14) In yet a further variant of the invention, a first flexible blanket is provided. The first blanket has an upper surface, a lower surface and is sized and shaped to cover the pressure vessel and extends outwardly beyond the outer edges thereof. The first blanket is fixedly attached at its lower surface to an upper surface of the pressure vessel. A second  
5 flexible blanket is provided. The second blanket has an upper surface, a lower surface and is sized and shaped to cover the pressure vessel and extends outwardly beyond the outer edges. The second blanket is fixedly attached at its upper surface to a lower surface of the pressure vessel. When the first and second flexible blankets are attached to the pressure vessel, the pressure handling capability of the pressure vessel will be increased.

10 (15) In another variant, heavy duty stitching is used to attach the first blanket to the second blanket. The stitching penetrates the first and second blankets and serves to further reinforce and increase the pressure-handling capabilities of the pressure vessel.

(16) In still another variant, the heavy duty stitching is high pressure hoop and lock braiding.

15 (17) In still a further variant of the invention, the cross-sectional shape of the outer surface of the flexible tubing is selected from the group comprising: square, triangular, round, hexagonal, ovoid, octagonal and star-shaped.

(18) In yet a further variant of the invention, the cross-sectional shape of the inner surface of the flexible tubing is selected from the group comprising: square, triangle, round,  
20 hexagonal, ovoid, octagonal, and star-shaped.

(19) In still a further variant of the invention, the cross-sectional shape of the flexible pressure vessel is selected from the group comprising: square, triangular, round, hexagonal, ovoid, octagonal, pillow-shaped, saddle-shaped, and a flattened mat shape.

(20) In yet a further variant of the invention, each of the receptacles are of a concave  
5 form selected from the group comprising: conical, dome-shaped, ellipsoid and stair-stepped.

(21) In a variant, the first and second ends of each of the flexible tubes are sized and shaped to fit sealably into the receptacles.

(22) In still a further variant of the invention, upper and lower reinforcing panels are provided. The reinforcing panels are formed of high-strength woven material and are shaped  
10 as a form to cover at least half of a surface area of the pressure vessel with extensions projecting from a perimeter of the form. The reinforcing panels are adhered to an outer surface of the pressure vessel, thereby increasing the pressure handling capability of the pressure vessel.

(23) In a variant, the method of adhesion is selected from the group comprising: high-  
15 strength adhesive, sonic welding and RF welding.

(24) In another variant, the woven material is prepregated with either adhesive or laminating material and subjected to heat and pressure.

(25) An apparatus for fabricating a cellular reservoir flexible pressure vessel may be constructed from the following components. A raw plastic storage and feeding unit is  
20 provided. The storage and feeding unit contains a supply of raw plastic. A multi-head extruder is provided. The extruder includes a heating facility and is in communication with the feeding unit. A cooling tank is provided. The cooling tank is located downstream from

the extruder. A power puller is provided. The puller serves to pull a tubing bundle from the cooling tank. Core tubing forming dies are provided. The forming dies form the tubing bundle into a predetermined shape. A binder head is provided. The binder head has an attached binder tank containing liquid binder material. A binder applicator is provided. The binder applicator comprises a secondary forming die and serves to affix the binder material to the tubing bundle. A cutting unit is provided. The cutting unit comprises a laser calibration facility and serves to cut the tubing bundle to a predetermined length. A conveyer facility is provided. The conveyer facility comprises means for positioning a cut tubing bundle. A rotating head and ram is provided. The head comprises a glue head applicator. The glue head applicator attaches to a glue tank. A plurality of preformed end caps are provided. An automated end cap loader is provided. The end cap loader positions the plurality of end caps. An automated end cap installer attached to the automated end cap loader is provided. The installer serves to attach the end caps to the tubing bundle. A high-intensity UV lamp assembly is provided. The lamp assembly serves to cure the glue.

(26) In a variant of the apparatus for fabricating a cellular reservoir flexible pressure vessel, a plurality of reinforcing rings is provided. The reinforcing rings are formed of high-strength material. A reinforcing ring auto loader is provided. A swivel ram is provided. The ram comprises of a ring loading and placement head. The swivel ram is in cooperation with the ring auto loader and serves to press the reinforcing ring onto the pressure vessel.

(27) In another variant of the apparatus for fabricating a cellular reservoir flexible pressure vessel, either a gas or liquid supply tank is provided. An auto loader test head is provided. The test head is adaptable to fittings on the end caps. A cryogenic test unit in

communication with the test head is provided. The test head and the test unit provides means for pressurizing the pressure vessel.

(28) In yet a further variant of the apparatus for fabricating a cellular reservoir flexible pressure vessel, a reinforcing blanket material is provided. A glue spraying mechanism is provided. The mechanism comprises of glue tanks, glue spray heads and glue for attaching the blanket material to the pressure vessel. A blanket material feed mechanism is provided. A press forming tool is provided. The tool is adapted to form the blanket material over the cut tubing bundle and the attached end caps.

(29) In a variant, a high-strength thread is provided. A stitching head is provided. The stitching head is adapted to sew the high-strength thread through the reinforcing blanket material.

(30) In still a further variant of the apparatus for fabricating a cellular reservoir flexible pressure vessel, a high-strength braiding material is provided. A braider is provided. The braider is adapted to position and provide overwrapping of the pressure vessel with the braiding material. A binder spraying mechanism is provided. The spraying mechanism comprises of a binder tank, a binder spray head and binder material.

(31) In yet a further variant of the apparatus for fabricating a cellular reservoir flexible pressure vessel, a high-strength reinforcing ribbon is provided. An automated reinforcing ribbon winding machine is provided. The winding machine comprises of a reinforcing ribbon spool and an auto layout ribbon head. A binder spraying mechanism is provided. The spraying machine comprises of a binder tank, a binder spray head and binder material.

(32) In still a further variant of the apparatus for fabricating a cellular reservoir flexible pressure vessel, means are provided for pulling a series of high tensile strength core wires through orifices in receptacles in the end cap to a passageway in the end cap. Means are provided for injecting syntactic foam through an opening in the end cap. Means are provided for attaching a sealing plug to the opening. Means are provided for removing the core wires from the end cap. When the core wires are removed from the end cap, a series of canals will be formed in the syntactic foam connecting orifices in receptacles in the end cap to the passageway.

(33) In yet a further variant of the apparatus for fabricating a cellular reservoir flexible pressure vessel, means are provided for attaching a series of flexible microtubes to orifices in receptacles in the end cap to a passageway in the end cap. Means are provided for injecting syntactic foam through an opening in the end cap. Means are provided for attaching a sealing plug to the opening. Means are provided for removing the core wires from the end cap. When the microtubes are connected to the passageway, the pressure vessel will provide an ultra clean environment for either liquids or gasses.

(34) In still a further variant of the apparatus for fabricating a cellular reservoir flexible pressure vessel, means are provided for forming a concave receptacle having a shape selected from the group comprising: conical, dome-shaped, ellipsoid and stair-stepped.

(35) In a variant, means are provided for forming the first and second ends of each of the flexible tubes to fit sealably into the receptacles.

(36) In yet a further variant of the apparatus for fabricating a cellular reservoir flexible pressure vessel, means are provided for forming upper and lower reinforcing panels. The

reinforcing panels are formed of high-strength woven material and are shaped as a form to cover at least half of a surface area of the pressure vessel with extensions projecting from a perimeter from the form. Means are provided for adhering the reinforcing panel to the outer surface of the pressure vessel, thereby increasing the pressure handling capability of the pressure vessel.

(37) In a variant of the apparatus for fabricating a cellular reservoir flexible pressure vessel, the method of adhesion is selected from the group comprising: high-strength adhesive, sonic welding and RF welding.

(38) In another variant of the apparatus for fabricating a cellular reservoir flexible pressure vessel, the woven material is prepregnated with either adhesive or laminating material and subjected to heat and pressure.

(53) In yet another variant of the invention, the cellular reservoir flexible pressure vessel, has a first pressure relief device. The first pressure relief device is located on an inner surface of either the first or second end caps and includes a reduction in thickness of the end cap at a predetermined location. When the pressure vessel is subjected to an overpressure condition, it will fail at the predetermined location.

(54) In still another variant of the invention, the first pressure relief device has an indentation in the inner surface of either the first or second end caps. The indentation has side walls angled inwardly from the inner surface.

(55) In still a further variant of the invention, the cellular reservoir flexible pressure vessel has a second pressure relief device. The second pressure relief device is located on an outer surface of the flexible pressure vessel and has at least one projecting member. The

projecting member is sized and shaped to penetrate the high-strength braiding material at a predetermined location. When the high-strength braiding material is penetrated by the projecting member and the flexible pressure vessel is subjected to an overpressure condition, the vessel will fail at the predetermined location.

5           (56) In an additional variant, the projecting member is removably attached to the outer surface of the flexible pressure vessel.

          (57) In another variant, the cellular reservoir flexible pressure vessel has a second pressure relief device. The second pressure relief device is located on an outer surface of the flexible pressure vessel and has at least one projecting member. The projecting member is  
10   sized and shaped to penetrate the high-strength material at a predetermined location. When the high-strength material is penetrated by the projecting member and the flexible pressure vessel is subjected to an overpressure condition, the vessel will fail at the predetermined location.

          (58) In a further variant, the projecting member is removably attached to the outer  
15   surface of the flexible pressure vessel.

          (59) In still a further variant, the cellular reservoir flexible pressure vessel has a second pressure relief device. The second pressure relief device is located on an outer surface of the flexible pressure vessel and has at least one projecting member. The projecting member is sized and shaped to penetrate either the first or second flexible blankets at a predetermined  
20   location. When either the first or second flexible blanket is penetrated by the projecting member and the flexible pressure vessel is subjected to an overpressure condition, the vessel will fail at the predetermined location.

(60) In another variant of the invention, the projecting member is removably attached to the outer surface of the flexible pressure vessel.

(61) In an additional variant of the invention, the ovoid flexible pressure vessel has a second pressure relief device. The second pressure relief device is located on the outer surface of the flexible pressure vessel and has at least one projecting member. The projecting member is sized and shaped to penetrate either the upper or lower reinforcing panels at a predetermined location. When either the upper or lower reinforcing panel is penetrated by the projecting member and the flexible pressure vessel is subjected to an overpressure condition, the vessel will fail at the predetermined location.

(62) In a further variant of the invention, the projecting member is removably attached to the outer surface of the flexible pressure vessel.

(63) In still a further variant of the invention, the cellular reservoir flexible pressure vessel has a third pressure relief device. The third pressure relief device has a weakened section of the passageway. When the flexible pressure vessel is subjected to an overpressure condition, the flexible pressure vessel will fail at the weakened section of the passageway.

(64) In another variant, the weakened section of the passageway has a smaller cross-sectional area than a balance of the passageway.

(65) In an additional variant, the cellular reservoir flexible pressure vessel has high-strength braiding material wound about the passageway, thereby providing additional resistance to pressure for the flexible pressure vessel.

(66) In a further variant, the cellular reservoir flexible pressure vessel has a fourth pressure relief device. The fourth pressure relief device has either a weakening or an absence



of high-strength braiding material at a predetermined location along the passageway. When the flexible pressure vessel is subjected to an overpressure condition, the flexible pressure vessel will fail at the predetermined location along the passageway.

(67) In still a further variant, the cellular reservoir flexible pressure vessel has hoop  
5 winding about the passageway, thereby providing additional resistance to pressure to the flexible pressure vessel.

(68) In another variant of the invention, the cellular reservoir flexible pressure vessel has a fifth pressure relief device. The fifth pressure relief device has either a weakening or an absence of hoop winding at a predetermined location along the passageway. When the  
10 flexible pressure vessel is subjected to an overpressure condition, the pressure vessel will fail at the predetermined location along the passageway.

(69) In an additional variant, the cellular reservoir flexible pressure vessel has either a weakening or a spreading of fibers in the high-strength braiding material at a predetermined location. The predetermined location is above an outer surface of the pressure vessel. When  
15 the high-strength braiding material has the fibers weakened or spread in the predetermined location and the pressure vessel is subjected to an overpressure condition, the pressure vessel will fail at the predetermined location.

(70) In a further variant, the cellular reservoir flexible pressure vessel has either a weakening or a spreading of fibers in the high-strength material at a predetermined location.  
20 The predetermined location is above an outer surface of the pressure vessel. When the high-strength material has the fibers weakened or spread in the predetermined location and the

pressure vessel is subjected to an overpressure condition, the pressure vessel will fail at the predetermined location.

(71) In still a further variant, the cellular reservoir flexible pressure vessel has either a weakening or a spreading of fibers in either of the first flexible blanket and the second flexible  
5 blanket at a predetermined location. The predetermined location is above an outer surface of the pressure vessel. When either of the first flexible blanket and the second flexible blanket has the fibers weakened or spread in the predetermined location and the pressure vessel is subjected to an overpressure condition, the pressure vessel will fail at the predetermined location.

10 (72) In another variant of the invention, the cellular reservoir flexible pressure vessel has either a weakening or a spreading of fibers in either the upper or lower reinforcing panels at a predetermined location. The predetermined location is above the outer surface of the pressure vessel. When either of the upper or lower reinforcing panels has the fibers weakened or spread in the predetermined location and the pressure vessel is subjected to an overpressure  
15 condition, the pressure vessel will fail at the predetermined location.

(73) In an additional variant, the connection to either a passageway of another vessel or a valve further has a capillary tube. The capillary tube has a proximate end and a distal end and is formed of resilient material and sized and shaped to fit slidably within the passageway. High-strength braiding material is provided. The braiding material is located about the  
20 capillary tube and extends along the capillary tube to within a first predetermined distance from the proximate end. The proximate end of the braiding covered capillary tube is inserted into the passageway and is either radio frequency welded or secured with adhesive to it.

When the proximate end of the capillary tube is either welded or secured with adhesive within the passageway, it will be permanently attached to it.

(74) In a further variant of the invention, an apparatus for modifying reinforcing panel material is provided. The apparatus has means for supporting a supply roll of flexible blanket material. Means for moving the flexible blanket material from the supply roll to a work area is provided. Means for tensioning the flexible blanket material in the work area is also provided. At least one separating member, which is sized and shaped to penetrate and separate fibers of the flexible blanket material is further provided.

Also provided is a means for moving the separating member into the tensioned flexible blanket material at a predetermined location in the material, thereby either weakening and separating the fibers. Means for retracting the separating member from the tensioned flexible blanket material is provided. Means for moving the flexible blanket material from work area to a storage area is provided. The flexible blanket material will have either a weakened or separated fibers in the predetermined location prior to application to the pressure vessel.

(75) In still a further variant of the invention, an apparatus for modifying reinforcing panel material is provided. The apparatus has means for supporting a supply roll of reinforcing panel material. Means for moving the reinforcing panel material from the supply roll to a work area is provided. Means for tensioning the reinforcing panel material in the work area is provided. At least one separating member is provided. The separating member is sized and shaped to penetrate and separate fibers of the reinforcing panel material. Also provided are means for moving the separating member into the tensioned reinforcing panel material at a predetermined location in the material, thereby either weakening or separating

the fibers. Means for retracting the separating member from the tensioned reinforcing panel material is provided. Means for moving the reinforcing panel material from work area to a storage area is provided. The reinforcing panel material will have either weakened or separated fibers in the predetermined location prior to application to the pressure vessel.

5           (76) In another variant, a method for making the cellular reservoir flexible pressure vessel is provided. The method has the following steps: providing a supply roll of flexible blanket material; supporting the supply roll; moving the flexible blanket material from the supply roll to a work area; tensioning the flexible blanket material in the work area; providing at least one separating member, where the member is sized and shaped to penetrate and  
10   separate fibers of the flexible blanket material; moving the separating member into the tensioned flexible blanket material at a predetermined location in the material, thereby either weakening or separating the fibers; retracting the separating member from the tensioned flexible blanket material; moving the flexible blanket material from work area to a storage area. The flexible blanket material will have either weakened or separated fibers in the  
15   predetermined location prior to application to the pressure vessel.

          (77) In a final variant, a method for making the cellular reservoir flexible pressure vessel has the following steps: providing a supply roll of reinforcing panel material; providing means for supporting the supply roll; moving the reinforcing panel material from the supply roll to a work area; tensioning the reinforcing panel material in the work area;  
20   providing at least one separating member, where the member is sized and shaped to penetrate and separate fibers of the reinforcing panel material; moving the separating member into the tensioned reinforcing panel material at a predetermined location in the material, thereby either

weakening or separating the fibers; retracting the separating member from the tensioned reinforcing panel material; moving the reinforcing panel material from work area to a storage area. The reinforcing panel material will have either weakened or separated fibers in the predetermined location prior to application to the pressure vessel.

5

Description of the Drawings

**Figure 1** is a plan view of a first embodiment of the invention illustrating cellular reservoir cells, first and second end caps, a connecting passageways and a valve;

5        **Figure 2** is a cross-sectional view of the **Figure 1** embodiment taken along the line 2-2;

**Figure 2A** is an end cross-sectional view of the **Figure 1** embodiment taken along the line 2A-2A;

10        **Figure 3** is an end view of the **Figure 1** embodiment taken along the line 3-3 illustrating a first embodiment of a reinforcing ring, an aperture in the ring and a cross-section of the ring in partial cutaway;

**Figure 3A** is a side elevational view of the **Figure 1** embodiment, illustrating a first embodiment of upper and lower reinforcing rings;

15        **Figure 4** is a partial cross-sectional view of the **Figure 3A** embodiment taken along the line 4-4;

**Figure 5** is a partial cross-sectional view of the **Figure 3A** embodiment illustrating a means for fastening the upper and lower reinforcing rings together;

**Figure 6** is a partial cross-sectional view of a second embodiment of upper and lower reinforcing rings illustrating grooves and ribs for attaching the rings;

20        **Figure 7** is a partial cross-sectional view of a third embodiment of upper and lower reinforcing rings illustrating grooves and ribs for attaching the rings and means for attaching the rings together;

**Figure 8** is a cross-sectional view of an end cap illustrating means for introducing syntactic foam into the end cap and wires for forming canals through the foam;

**Figure 9** is a cross-sectional view of an end cap illustrating microtubes connecting the receptacles to the passageway and a sealing plug for closing the end cap after introduction of  
5 the syntactic foam;

**Figure 10** is a side elevational view of the **Figure 1** embodiment illustrating an overwrapping of high-strength braiding material;

**Figure 11** is a side elevational view of the **Figure 1** embodiment illustrating hoop winding;

10 **Figure 12** is a partial cross-sectional view of the **Figure 1** embodiment illustrating a plastic overcoating;

**Figure 13** cross-sectional view of the **Figure 1** embodiment illustrating flexible blankets attached to the pressure vessel;

**Figure 14** is a plan view of the **Figure 1** embodiment illustrating high-strength  
15 stitching of the flexible blankets;

**Figure 15A** is a cross-sectional view of a cellular reservoir tube having a hexagonal external cross-section;

**Figure 15B** is a cross-sectional view of a cellular reservoir tube having a square external cross-section;

20 **Figure 15C** is a cross-sectional view of a cellular reservoir tube having a equilateral triangular external cross-section;

**Figure 15D** is a cross-sectional view of a cellular reservoir tube having an oval external cross-section;

**Figure 15E** is a cross-sectional view of a cellular reservoir tube having a right triangular external cross-section;

5        **Figure 15F** is a cross-sectional view of a cellular reservoir tube having a round external cross-section;

**Figure 15G** is a cross-sectional view of a cellular reservoir tube having a octagonal external cross-section;

10       **Figure 15H** is a cross-sectional view of a cellular reservoir tube having a star-shaped external cross-section;

**Figure 16A** is a cross-sectional view of a cellular reservoir tube having a hexagonal internal cross-section;

**Figure 16B** is a cross-sectional view of a cellular reservoir tube having a square internal cross-section;

15       **Figure 16C** is a cross-sectional view of a cellular reservoir tube having a equilateral triangular internal cross-section;

**Figure 16D** is a cross-sectional view of a cellular reservoir tube having an oval internal cross-section;

20       **Figure 16E** is a cross-sectional view of a cellular reservoir tube having a right triangular internal cross-section;

**Figure 16F** is a cross-sectional view of a cellular reservoir tube having a round internal cross-section;



**Figure 16G** is a cross-sectional view of a cellular reservoir tube having a octagonal internal cross-section;

**Figure 16H** is a cross-sectional view of a cellular reservoir tube having a star-shaped internal cross-section;

5        **Figure 17A** is a cross-sectional view of a cellular reservoir flexible pressure vessel having a hexagonal shape;

**Figure 17B** is a cross-sectional view of a cellular reservoir flexible pressure vessel having a square shape;

10       **Figure 17C** is a cross-sectional view of a cellular reservoir flexible pressure vessel having an equilateral triangular shape;

**Figure 17D** is a cross-sectional view of a cellular reservoir flexible pressure vessel having an oval shape;

**Figure 17E** is a cross-sectional view of a cellular reservoir flexible pressure vessel having an airfoil shape;

15       **Figure 17F** is a cross-sectional view of a cellular reservoir flexible pressure vessel having a right triangular shape;

**Figure 17G** is a cross-sectional view of a cellular reservoir flexible pressure vessel having a round shape;

20       **Figure 17H** is a cross-sectional view of a cellular reservoir flexible pressure vessel having a octagonal shape;

**Figure 17I** is a cross-sectional view of a cellular reservoir flexible pressure vessel having a saddle shape;

**Figure 17J** is a cross-sectional view of a cellular reservoir flexible pressure vessel having a flat mat shape;

**Figure 18A** is a cross-sectional view of a receptacle and fitting square-shaped flexible tube end;

5        **Figure 18B** is a cross-sectional view of a receptacle and fitting cone-shaped flexible tube end;

**Figure 18C** is a cross-sectional view of a receptacle and fitting hemi-spherical-shaped flexible tube end;

10       **Figure 18D** is a cross-sectional view of a receptacle and fitting step-shaped flexible tube end;

**Figure 18E** is a cross-sectional view of a receptacle and fitting bullet-shaped flexible tube end;

**Figure 19** is a side elevational view of the **Figure 1** embodiment enclosed in upper and lower reinforcing panels;

15       **Figure 20** is a plan view of the **Figure 1** embodiment on upper and lower reinforcing panels prior to attachment;

**Figure 21** is a side elevational view of an apparatus for fabricating flexible tubes for a cellular reservoir flexible pressure vessel;

20       **Figure 22** is a side elevational view of an apparatus for attaching the end caps to the flexible tubes;

**Figure 23** is a side elevational view of an apparatus for curing the adhesive for the flexible tubes and attaching the reinforcing rings;

**Figure 24** is a side elevational view of apparatus for filling the vessel with cryogenic liquid or gas, attaching high-strength blanket material and stitching high-strength thread through the reinforcing blanket material;

**Figure 25** is a side elevational view of an apparatus for overwrapping of the pressure  
5 vessel with high-strength braiding material;

**Figure 26** is a side elevational view of an apparatus for hoop winding reinforcing ribbon onto the pressure vessel;

**Figure 27** is a side cross-sectional view of an apparatus for pulling wires into the end cap prior to injection of syntactic foam to leave canals;

10 **Figure 28** is a side cross-sectional view of an apparatus for pulling microtubes into the end cap prior to injection of syntactic foam;

**Figure 29** is a detailed side cross-sectional view of an apparatus for forming a concave receptacle having a dome shape;

**Figure 29A** is a side cross-sectional view of an apparatus for a series of concave  
15 receptacles having a dome shape;

**Figure 30** is a side cross-sectional view of an apparatus for forming the first and second ends of each of said flexible tubes to fit sealably into said receptacles;

**Figure 31** is a perspective view of an apparatus for forming reinforcing panels;

**Figure 32** is a perspective view of an apparatus for applying adhesive to a reinforcing  
20 panel;

**Figure 33** is a plan view of an embodiment of the invention illustrating a first pressure relief device located on an inner surface of an end cap;

**Figure 34** is a cross-sectional view of the **Figure 33** embodiment taken along the line 34-34, illustrating the first pressure relief device on the inner surface of the end cap;

**Figure 35** is a plan view of an embodiment of the invention illustrating a second pressure relief device located on an outer surface of an end cap;

5        **Figure 36** is a cross sectional view of the **Figure 35** embodiment of the invention taken along the line 36-36 illustrating the second pressure relief device that has at least one projecting member;

10       **Figure 37** is a plan view of an embodiment of the invention illustrating penetration of the second pressure relief device through the high strength braiding material at a predetermined location;

**Figure 38** is a plan view of the **Figure 35** embodiment illustrating a second pressure relief device which is removably attached;

**Figure 39** is a cross-sectional view of the **Figure 38** embodiment taken along the line 39-39;

15       **Figure 40** is a side elevational view of an apparatus for modifying flexible blanket material and for modifying reinforcing panel material;

**Figure 40A** is perspective view of the **Figure 40** apparatus illustrating the modified fabric or blanket material;

20       **Figure 41** is a plan view of a reinforcing panel with either a weakening or spreading of fibers at a predetermined location;

**Figure 42** is a partial detail view of a reinforcing panel or high strength braiding material with either a weakening or spreading of fibers at a predetermined location;

**Figure 43** is a cross-sectional view of an embodiment illustrating a third pressure relief device with a weakened section of the passageway;

**Figure 44** is a partial detailed view of the **Figure 43** embodiment taken along the line 44-44 illustrating the third pressure relief device;

5        **Figure 45** is a cross-sectional view of an embodiment illustrating the connection of a capillary tube to a passageway and to an end cap prior to insertion and welding;

**Figure 46** is a cross-sectional view of the **Figure 45** embodiment illustrating attachment of the capillary tube to the passageway and end cap;

10       **Figure 47** is a plan view of the **Figure 33** embodiment illustrating the weakening or spreading of fibers in the flexible blanket at predetermined location;

**Figure 48** is a cross-sectional view of the **Figure 47** embodiment illustrating the a weakening or spreading of fibers in the flexible blanket at predetermined location;

15       **Figure 49** is a cross-sectional view of an embodiment with high strength braiding material wound about the passageway providing additional resistance to pressure for the pressure vessel;

**Figure 50** is a cross-sectional view of the **Figure 49** embodiment illustrating a fourth pressure relief device that has either an absence or a weakening of high strength braiding material at a predetermined location on the passageway;

20       **Figure 51** is a cross-sectional view of an embodiment with hoop winding about the passageway providing additional resistance to pressure for the pressure vessel; and

**Figure 52** is a cross-sectional view of the **Figure 51** embodiment illustrating a fourth pressure relief device that has either an absence or a weakening of hoop winding at a predetermined location on the passageway.

## 5 Detailed Description of the Preferred Embodiment

(1) A cellular reservoir flexible pressure vessel **10** providing the desired features, as shown in **Figures 1, 2** and **2A**, may be constructed from the following components. A plurality of flexible tubes **15** is provided. Each of the flexible tubes **15** are formed of resilient material **20** and has an outer surface **25**, an inner surface **30**, a first end **35** and a second end

10 **40**.

First **45** and second **50** end caps are provided. Each of the end caps **45, 50** has a receptacle **55** for either of the first **35** or second **40** ends of each of the flexible tubes **15**, a collecting reservoir **70**, a surrounding outer rim **75** and an outer perimeter **80** perpendicular to the surrounding outer rim **75**. At least one of the first **45** and second **50** end caps has a

15 passageway **85** connecting to the collecting reservoir **70** as a connection **88** to either a passageway **85** of another pressure vessel **10** or a valve **90**. Each of the receptacles **55** has a surrounding wall **95**, a base **100** and an orifice **105** penetrating the base **100**. The orifice **105** connects the receptacle **55** to either the collecting reservoir **70** or the passageway **85**. The wall

20 **95** has an interior surface **110**. The interior surface **110** is sized and shaped to fit frictionally over the outer surface **25** of one of the flexible tubes **15** at either the first **35** or second **40** ends. The collecting reservoir **70** has an outer surface **115** and connects the base **100** of each of the receptacles **55** to a common space **120**. The common space **120** is either closed or

connected to the passageway **85**. The surrounding outer rim **75** extends outwardly from the outer surface **115** of the collecting reservoir **70** for a first predetermined distance **125** along the flexible tubes **15** and serves to constrain the flexible tubes **15**.

Means **130** are provided for securing the first **45** and second **50** end caps to the flexible tubes **15**. A valving means **135** is provided. The valving means **135** is capable of controlling a flow of either a liquid or a gas through the passageway **85** and is attached to a distal end **150** of the passageway **85**. When the flexible tubes **15** are inserted into the receptacles **55** of the end caps **45, 50** and secured thereto, a flexible pressure vessel **10** will be formed capable of containing either a liquid or a gas at high pressure.

(2) In a variant of the invention, as shown in **Figures 1-2**, the means **130** for securing the first **45** and second **50** end caps to the flexible tubes **15** is selected from the group comprising: radio frequency welding, high-strength adhesive, mechanical fastening and sonic welding.

(3) In another variant of the invention, as shown in **Figure 3**, a protruding rim **180** is provided. The protruding rim **180** is located at the outer perimeter **80** of the first **45** and second **50** end caps and upper **185** and lower **190** receiving notches located above and below the protruding rim **180**. A reinforcing ring **195** is provided. The reinforcing ring **195** has an inner surface **200**, an outer surface **205** and is formed of high-strength material **206**. The reinforcing ring **195** is sized and shaped to fit tightly about the outer perimeter **80** of the end caps **45, 50**. The reinforcing ring **195** has an upper **210** and lower **215** projecting ribs and a central receiving notch **220** located between the upper **210** and lower **215** projecting ribs. The projecting ribs **210, 215** are sized, shaped and located to fit the upper **185** and lower **190**

receiving notches of the end caps **45, 50**. The central receiving notch **220** is sized, shaped and located to fit the protruding rim **180** of the end caps **45, 50**. The reinforcing ring **195** has an aperture **225**. The aperture **225** extends from the inner surface **200** to the outer surface **205** and is sized, shaped and located to accommodate the passageway **85** of the end caps **45, 50**.

- 5 When the reinforcing ring **195** is located about the outer perimeter **80** of the first **45** and second **50** end caps, the pressure handling capacity of the pressure vessel **10** is increased.

(4) In yet a further variant of the invention, as shown in **Figure 3A** and **Figure 4**, a protruding rim **180** is provided. The protruding rim **180** is located at the outer perimeter **80** of the first **45** and second **50** end caps. Upper **185** and lower **190** receiving notches are provided.

- 10 The upper **185** and lower **190** receiving notches are located above and below the protruding rim **180**.

Upper **230** and lower **235** reinforcing rings are provided. Each of the reinforcing rings **230, 235** has an inner surface **240**, an outer surface **245** and is formed of high-strength material **246**. The upper **230** and lower **235** reinforcing rings are sized and shaped to fit

15 tightly in either of the upper **185** and lower **190** receiving notches. At least one of the reinforcing rings **230, 235** has an aperture **250**. The aperture **250** extends from the inner surface **240** to the outer surface **245** and is sized, shaped and located to accommodate the passageway **85** connecting to the collecting reservoir **70**. When the reinforcing rings **230, 235** are located about the outer perimeter **80** of the first **45** and second **50** end caps, the pressure

20 handling capacity of the pressure vessel **10** is increased.

(5) In another variant of the invention, as shown in **Figure 5**, means **255** are provided for fastening the upper reinforcing ring **230** to the lower reinforcing ring **235**.



(6) In still a further variant of the invention, as shown in **Figure 6**, a protruding rim **180** is provided. The protruding rim **180** is located at the outer perimeter **80** of the first **45** and second **50** end caps. At least one groove **260** located about the outer perimeter **80** above the protruding rim **180** is provided. At least one groove **260** located about the outer perimeter **80** below the protruding rim **180** is provided. Upper **230** and lower **235** reinforcing rings are provided. Each of the reinforcing rings **230**, **235** has an inner surface **240**, an outer surface **245** and is formed of high-strength material **246**. Each of the upper **230** and lower **235** reinforcing rings is sized and shaped to fit tightly about the outer perimeter **80** on either side of the protruding rim **180**. Each of the reinforcing rings **230**, **235** has at least one rib **265** located upon the inner surface **240** thereof. The rib **265** is sized, shaped and located to engage the groove **260**. When the reinforcing rings **230**, **235** are located about the outer perimeter **80** of the first **45** and second **50** end caps, the pressure handling capacity of the pressure vessel **10** is increased.

(7) In another variant of the invention, as shown in **Figure 7**, means **255** are provided for fastening the upper reinforcing ring **230** to the lower reinforcing ring **235**.

(8) In yet a further variant of the invention, as shown in **Figure 8**, a syntactic foam filler **270** is provided. The foam filler **270** is located within the collecting reservoir **70** of at least one of the first **45** and second **50** end caps. The foam filler **270** has a series of canals **275** through it. Each of the canals **275** connects the orifice **105** of the receptacle **55** to the passageway **85**. An opening **285** in the end caps **45**, **50** is provided. The opening **285** provides means **286** for introduction of the foam filler **270** into the end caps **45**, **50**. A sealing plug **290** is provided. The sealing plug **290** is sized and shaped to fit sealably into the opening

285 in the end caps 45, 50. When the foam filler 270 is introduced into the end caps 45, 50, the pressure handling capacity of the pressure vessel 10 is increased.

(9) In still a further variant of the invention, as shown in **Figure 9**, a syntactic foam filler 270 is provided. The foam filler 270 is located within the collecting reservoir 70 of at least one of the first 45 and second 50 end caps. The foam filler 270 is penetrated by a series of flexible microtubes 291. Each of the microtubes 291 connects the orifice 105 of the receptacle 55 to the passageway 85. An opening 285 in the end caps 45, 50 is provided. The opening 285 provides means 286 for introduction of the syntactic foam 270 into the end caps 45, 50. A sealing plug 290 is provided. The sealing plug 290 is sized and shaped to fit sealably into the opening 285 in the end caps 45, 50. When the microtubes 291 are connected to the orifices 105 of the receptacles 55 in the end caps 45, 50, the purity of either liquids or gasses stored in the pressure vessel 10 is increased.

(10) In yet a further variant of the invention, as shown in **Figure 10**, an overwrapping of high-strength braiding material 295 is provided. The braiding material 295 extends over the flexible tubes 15 and the first 45 and second 50 end caps. When the flexible pressure vessel 10 is so overwrapped, its pressure-handling capability will be increased.

(11) In still a further variant of the invention, as shown in **Figure 11**, a hoop winding 305 with high-strength materials 306 is provided. The hoop winding 305 extends over the flexible tubes 15 and the first 45 and second 50 end caps. When the flexible pressure vessel 10 is so hoop wound, its pressure-handling capability will be increased.

(12) In another variant, as shown in **Figure 12**, a plastic overcoating **300** is provided. The overcoating **300** further increases the pressure-handling capability of the pressure vessel **10**.

(13) In another variant, as shown in **Figure 12**, a plastic overcoating **302** is provided. 5 The overcoating **302** further increases the pressure-handling capability of the pressure vessel **10**.

(14) In yet a further variant of the invention, as shown in **Figure 13**, a first flexible blanket **310** is provided. The first blanket **310** has an upper surface **315**, a lower surface **320** and is sized and shaped to cover the pressure vessel **10**. The first flexible blanket **310** extends 10 outwardly beyond the outer edges **325** thereof. The first blanket **310** is fixedly attached at its lower surface **320** to an upper surface **330** of the pressure vessel **10**. A second flexible blanket **335** is provided. The second blanket **335** has an upper surface **340**, a lower surface **345** and is sized and shaped to cover the pressure vessel **10**. The second flexible blanket **335** extends outwardly beyond the outer edges **326** thereof. The second blanket **335** is fixedly attached at 15 its upper surface **340** to a lower surface **355** of the pressure vessel **10**. When the first **310** and second **335** flexible blankets are attached to the pressure vessel **10**, the pressure handling capability of the pressure vessel **10** will be increased.

(15) In another variant, as shown in **Figure 14**, heavy duty stitching **360** is used to attach the first blanket **310** to the second **335** blanket. The stitching **360** penetrates the first 20 **310** and second blanket **335** and serves to further reinforce and increase the pressure-handling capabilities of the pressure vessel **10**.

(16) In still another variant, as shown in **Figure 14**, the heavy duty stitching **360** is high pressure hoop and lock braiding **380**.

(17) In still a further variant of the invention, as shown in **Figure 15A, Figure 15B, Figure 15C, Figure 15D, Figure 15E, Figure 15F, Figure 15G and Figure 15H**, the cross-sectional shape **385** of the outer surface **25** of the flexible tubing **15** is selected from the group comprising: square **390**, triangular **395**, round **400**, hexagonal **405**, ovoid **410**, octagonal **415** and star-shaped **420**.

(18) In yet a further variant of the invention, as shown in **Figure 16A, Figure 16B, Figure 16C, Figure 16D, Figure 16E, Figure 16F, Figure 16G and Figure 16H**, the cross-sectional shape **425** of the inner surface **30** of the flexible tubing **15** is selected from the group comprising: square **390**, triangle **395**, round **400**, hexagonal **405**, ovoid **410**, octagonal **415**, and star-shaped **420**.

(19) In still a further variant of the invention, as shown in **Figure 17A, Figure 17B, Figure 17C, Figure 17D, Figure 17E, Figure 17F, Figure 17G, Figure 17H, Figure 17I and Figure 17J**, the cross-sectional shape **430** of the flexible pressure vessel **10** is selected from the group comprising: square **390**, triangular **395**, round **400**, hexagonal **405**, ovoid **410**, octagonal **415**, pillow-shaped **470**, saddle-shaped **475**, and a flattened mat shape **480**.

(20) In yet a further variant of the invention, as shown in **Figure 18A, Figure 18B, Figure 18C, Figure 18D and Figure 18E**, each of the receptacles **55** are of a concave form **485** selected from the group comprising: conical **490**, dome-shaped **495**, ellipsoid **500** and stair-stepped **505**.

(21) In a variant, as shown in **Figure 18A**, **Figure 18B**, **Figure 18C**, **Figure 18D** and **Figure 18E**, the first **35** and second **40** ends of each of the flexible tubes **15** are sized and shaped to fit sealably into the receptacles **55**.

(22) In still a further variant of the invention, as shown in **Figure 19** and **Figure 20**,  
5 upper **510** and lower **515** reinforcing panels are provided. The reinforcing panels **510**, **515** are formed of high-strength woven material **520** and are shaped as a form **525** to cover at least half of a surface area **526** of the pressure vessel **10** with extensions **530** projecting from a perimeter **535** of the form **525**. The reinforcing panels **510**, **515** are joined to the outer surface **536** of the pressure vessel **10**, thereby increasing the pressure handling capability of the  
10 pressure vessel **10**.

(23) In a variant, the method of adhesion is selected from the group comprising: high-strength adhesive, sonic welding and RF welding.

(24) In another variant, as shown in **Figure 20**, the woven material **520** is prepregged with either adhesive or laminating material and subjected to heat and pressure.

15 (25) An apparatus for fabricating a cellular reservoir flexible pressure vessel **10** may be constructed, as shown in **Figure 21**, **Figure 22** and **Figure 23**, from the following components. A raw plastic storage and feeding unit **580** is provided. The storage and feeding unit **580** contains a supply of raw plastic **585**. A multi-head extruder **590** is provided. The extruder **590** includes a heating facility **595** and is in communication with the feeding unit  
20 **580**. A cooling tank **600** is provided. The cooling tank **600** is located downstream from the extruder **590**. A power puller **605** is provided. The puller **605** serves to pull a tubing bundle **610** from the cooling tank **600**. Core tubing forming dies **615** are provided. The forming dies

615 form the tubing bundle 610 into a predetermined shape 616. A binder head 620 is provided. The binder head 620 has an attached binder tank 625 containing liquid binder material 630. A binder applicator 635 is provided. The binder applicator 635 comprises a secondary forming die 640 and serves to affix the binder material 630 to the tubing bundle

5 610. A cutting unit 645 is provided. The cutting unit 645 comprises a laser calibration facility 650 and serves to cut the tubing bundle 610 to a predetermined length 655. A conveyer facility 660 is provided. The conveyer facility 660 comprises means 665 for positioning a cut tubing bundle 610. A rotating head and ram 670 is provided. The head 670 comprises a glue head applicator 675. The glue head applicator 675 attaches to a glue tank 680. A plurality of

10 preformed end caps 45, 50 are provided. An automated end cap loader 690 is provided. The end cap loader 690 positions the plurality of end caps 45, 50. An automated end cap installer 691 attached to the automated end cap loader 690 is provided. The installer 691 serves to attach the end caps 45, 50 to the tubing bundle 610. A high-intensity UV lamp assembly 695 is provided. The lamp assembly 695 serves to cure the glue 700.

15 (26) In a variant of the apparatus for fabricating a cellular reservoir flexible pressure vessel 10, as shown in **Figure 23**, a plurality of reinforcing rings 195 is provided. The reinforcing rings 195 are formed of high-strength material 206. A reinforcing ring auto loader 710 is provided. A swivel ram 715 is provided. The ram 715 comprises of a ring loading and placement head 720. The swivel ram 715 is in cooperation with the ring auto loader 710 and

20 serves to press the reinforcing ring 195 onto the pressure vessel 10.

(27) In another variant of the apparatus for fabricating a cellular reservoir flexible pressure vessel 10, as shown in **Figure 24**, either a gas or liquid supply tank 730 is provided.

An auto loader test head **735** is provided. The test head **735** is adaptable to fittings **736** on the end caps **45, 50**. A cryogenic test unit **740** in communication with the test head **735** is provided. The test head **735** and the test unit **740** provides means **745** for pressurizing the pressure vessel **10**.

5           (28) In yet a further variant of the apparatus for fabricating a cellular reservoir flexible pressure vessel **10**, as shown in **Figure 24**, reinforcing blanket material **750** is provided. A glue spraying mechanism **755** is provided. The mechanism **755** comprises glue tanks **760**, glue spray heads **765** and glue **766** for attaching the blanket material **750** to the pressure vessel **10**. A blanket material feed mechanism **775** is provided. A press forming tool **780** is  
10       provided. The tool **780** is adapted to form the blanket material **750** over the cut tubing bundle **610** and the attached end caps **45, 50**.

(29) In a variant, as shown in **Figure 24**, a high-strength thread **785** is provided. A stitching head **790** is provided. The stitching head **790** is adapted to sew the high-strength thread **785** through the reinforcing blanket material **750**.

15           (30) In still a further variant of the apparatus for fabricating a cellular reservoir flexible pressure vessel **10**, as shown in **Figure 25**, a high-strength braiding material **795** is provided. A braider **800** is provided. The braider **800** is adapted to position and provide overwrapping **805** of the pressure vessel **10** with the braiding material **795**. A binder spraying mechanism **810** is provided. The spraying mechanism **810** comprises a binder tank **815**, a binder spray  
20       head **820** and binder material **825**.

(31) In yet a further variant of the apparatus for fabricating a cellular reservoir flexible pressure vessel **10**, as shown in **Figure 26**, a high-strength reinforcing ribbon **830** is provided.

An automated reinforcing ribbon winding machine **835** is provided. The winding machine **835** comprises of a reinforcing ribbon spool **840** and an auto layout ribbon head **841**. A binder spraying mechanism **810** is provided. The spraying mechanism **810** comprises a binder tank **815**, a binder spray head **820** and binder material **825**.

5           (32) In still a further variant of the apparatus for fabricating a cellular reservoir flexible pressure vessel **10**, as shown in **Figure 27**, means **850** are provided for pulling a series of high tensile strength core wires **855** through orifices **105** in receptacles **55** in the end caps **45, 50** to a passageway **85** in the end caps **45, 50**. Means **286** are provided for injecting syntactic foam **270** through an opening **285** in the end caps **45, 50**. Means **880** are provided for attaching a  
10   sealing plug **290** to the opening **285**. Means **890** are provided for removing the core wires **855** from the end caps **45, 50**. When the core wires **855** are removed from the end caps **45, 50**, a series of canals **275** will be formed in the syntactic foam **270** connecting orifices **105** in receptacles **55** in the end caps **45, 50** to the passageway **85**.

          (33) In yet a further variant of the apparatus for fabricating a cellular reservoir flexible  
15   pressure vessel **10**, as shown in **Figure 28**, means **900** are provided for attaching a series of flexible microtubes **291** to orifices **105** in receptacles **55** in the end caps **45, 50** to a passageway **85** in the end caps **45, 50**. Means **286** are provided for injecting syntactic foam **270** through an opening **285** in the end caps **45, 50**. Means **880** are provided for attaching a  
20   sealing plug **290** to the opening **285**. Means **890** are provided for removing the core wires **855** from the end caps **45, 50**. When the microtubes **291** are connected to the passageway **85**, the pressure vessel **10** will provide an ultra clean environment for either liquids or gasses.



(34) In still a further variant of the apparatus for fabricating a cellular reservoir flexible pressure vessel 10, as shown in **Figures 18B, 18C, 18D, 18E, 29 and 29A**, means 930 are provided for forming a concave receptacle 485 having a shape selected from the group comprising: conical 490, dome-shaped 495, ellipsoid 500 and stair-stepped 505.

5 (35) In a variant, as shown in **Figure 30**, means 960 are provided for forming the first 35 and second 40 ends of each of the flexible tubes 15 to fit sealably into the receptacles 55.

(36) In yet a further variant of the apparatus for fabricating a cellular reservoir flexible pressure vessel 10, as shown in **Figure 31 and 32**, means 940 are provided for forming upper 510 and lower 515 reinforcing panels. The reinforcing panels 510, 515 are formed of high-  
10 strength woven material 520 and are shaped as a form 525 to cover at least half of a surface area 526 of the pressure vessel 10 with extensions 530 projecting from a perimeter 535 of the form 525. Means 531 are provided for adhering the reinforcing panels 510, 515 to the outer surface 536 of the pressure vessel 10, thereby increasing the pressure handling capability of the pressure vessel 10.

15 (37) In a variant, as shown in **Figure 32**, the method of adhesion is selected from the group comprising: high-strength adhesive, sonic welding and RF welding.

(38) In a another variant, the woven material 520 is prepregated with either adhesive or laminating material and subjected to heat and pressure.

(53) In yet another variant, as shown in **Figures 33 and 34**, the cellular reservoir  
20 flexible pressure vessel 10, has a first pressure relief device 1400. The first pressure relief device 1400 is located on an inner surface 1405 of either the first 45 or second 50 end caps and includes a reduction in thickness 1406 of the end cap 45, 50 at a predetermined location

**1410.** When the pressure vessel **10** is subjected to an overpressure condition, it will fail at the predetermined location **1410**.

(54) In still another variant, as shown in **Figures 33 and 34**, the first pressure relief device **1400** has an indentation **1415** in the inner surface **1405** of either the first **45** or second **50** end caps. The indentation **1415** has side walls **1420** angled inwardly from the inner surface **1405**.

(55) In still a further variant, as shown in **Figures 36, 37 and 42**, the cellular reservoir flexible pressure vessel **10** has a second pressure relief device **1425**. The second pressure relief device **1425** is located on an outer surface **536** of the flexible pressure vessel **10** and has at least one projecting member **1435**. The projecting member **1435** is sized and shaped to penetrate the high-strength braiding material **295** at a predetermined location **1410**. When the high-strength braiding material **295** is penetrated by the projecting member **1435** and the flexible pressure vessel **10** is subjected to an overpressure condition, the vessel **10** will fail at the predetermined location **1410**.

(56) In an additional variant, as shown in **Figures 38 and 39**, the projecting member **1435** is removably attached to the outer surface **536** of the flexible pressure vessel **10**.

(57) In another variant, as shown in **Figures 36, 37 and 42**, the cellular reservoir flexible pressure vessel **10** has a second pressure relief device **1425**. The second pressure relief device **1425** is located on an outer surface **536** of the flexible pressure vessel **10** and has at least one projecting member **1435**. The projecting member **1435** is sized and shaped to penetrate the high-strength material **306** at a predetermined location **1410**. When the high-strength material **306** is penetrated by the projecting member **1435** and the flexible pressure

vessel **10** is subjected to an overpressure condition, the vessel **10** will fail at the predetermined location **1410**.

(58) In a further variant, as shown in **Figures 38 and 39**, the projecting member **1435** is removably attached to the outer surface **536** of the flexible pressure vessel **10**.

5 (59) In still a further variant, as shown in **Figures 36 and 41**, the cellular reservoir flexible pressure vessel **10** has a second pressure relief device **1425**. The second pressure relief device **1425** is located on an outer surface **536** of the flexible pressure vessel **10** and has at least one projecting member **1435**. The projecting member **1435** is sized and shaped to penetrate either the first **310** or second **335** flexible blankets at a predetermined location **1410**.

10 When either the first **310** or second **335** flexible blanket is penetrated by the projecting member **1435** and the flexible pressure vessel **10** is subjected to an overpressure condition, the vessel **10** will fail at the predetermined location **1410**.

(60) In another variant of the invention, as shown in **Figures 38 and 39**, the projecting member **1435** is removably attached to the outer surface **536** of the flexible pressure vessel **10**.

15 (61) In an additional variant of the invention, as shown in **Figures 36, 41 and 42**, the ovoid flexible pressure vessel **10** has a second pressure relief device **1425**. The second pressure relief device **1425** is located on the outer surface **536** of the flexible pressure vessel **10** and has at least one projecting member **1435**. The projecting member **1435** is sized and shaped to penetrate either the upper **510** or lower **515** reinforcing panels at a predetermined

20 location **1410**. When either the upper **510** or lower **515** reinforcing panel is penetrated by the projecting member **1435** and the flexible pressure vessel **10** is subjected to an overpressure condition, the vessel **10** will fail at the predetermined location **1410**.

(62) In a further variant of the invention, as shown in **Figures 38 and 39**, the projecting member **1435** is removably attached to the outer surface **536** of the flexible pressure vessel **10**.

(63) In still a further variant of the invention, as shown in **Figures 43 and 44**, the  
5 cellular reservoir flexible pressure vessel **10** has a third pressure relief device **990**. The third pressure relief device **990** has a weakened section **995** of the passageway **85**. When the flexible pressure vessel **10** is subjected to an overpressure condition, the flexible pressure vessel **10** will fail at the weakened section **995** of the passageway **85**.

(64) In another variant, as shown in **Figures 43 and 44**, the weakened section **995** of  
10 the passageway **85** has a smaller cross-sectional area **1000** than a balance of the passageway **85**.

(65) In an additional variant, as shown in **Figure 49**, the cellular reservoir flexible pressure vessel **10** has high-strength braiding material **295** wound about the passageway **85**, thereby providing additional resistance to pressure for the flexible pressure vessel **10**.

15 (66) In a further variant, as shown in **Figure 50**, the cellular reservoir flexible pressure vessel **10** has a fourth pressure relief device **1015**. The fourth pressure relief device **1015** has either a weakening or an absence of high-strength braiding material **295** at a predetermined location **1410** along the passageway **85**. When the flexible pressure vessel **10** is subjected to an overpressure condition, the flexible pressure vessel **10** will fail at the predetermined  
20 location **1410** along the passageway **85**.

(67) In still a further variant, as shown in **Figure 51**, the cellular reservoir flexible pressure vessel **10** has hoop winding **305** about the passageway **85**, thereby providing additional resistance to pressure to the flexible pressure vessel **10**.

(68) In another variant of the invention, as shown in **Figure 52**, the cellular reservoir flexible pressure vessel **10** has a fifth pressure relief device **1030**. The fifth pressure relief device **1030** has either a weakening or an absence of hoop winding **305** at a predetermined location **1410** along the passageway **85**. When the flexible pressure vessel **10** is subjected to an overpressure condition, the pressure vessel **10** will fail at the predetermined location **1410** along the passageway **85**.

(69) In an additional variant, as shown in **Figure 42**, the cellular reservoir flexible pressure vessel **10** has either a weakening or a spreading of fibers **1040** in the high-strength braiding material **295** at a predetermined location **1410**. The predetermined location **1410** is above an outer surface **536** of the pressure vessel **10**. When the high-strength braiding material **295** has the fibers **1040** weakened or spread in the predetermined location **1410** and the pressure vessel **10** is subjected to an overpressure condition, the pressure vessel **10** will fail at the predetermined location **1410**.

(70) In a further variant, as shown in **Figure 42**, the cellular reservoir flexible pressure vessel **10** has either a weakening or a spreading of fibers **1055** in the high-strength material **306** at a predetermined location **1410**. The predetermined location **1410** is above an outer surface **536** of the pressure vessel **10**. When the high-strength material **306** has the fibers **1055** weakened or spread in the predetermined location **1410** and the pressure vessel **10** is

subjected to an overpressure condition, the pressure vessel **10** will fail at the predetermined location **1410**.

(71) In still a further variant, as shown in **Figures 47 and 48**, the cellular reservoir flexible pressure vessel **10** has either a weakening or a spreading of fibers **1055** in either the first flexible blanket **310** or the second flexible blanket **335** at a predetermined location **1410**. The predetermined location **1410** is above an outer surface **536** of the pressure vessel **10**. When either of the first flexible blanket **310** and the second flexible blanket **335** has the fibers **1055** weakened or spread in the predetermined location **1410** and the pressure vessel **10** is subjected to an overpressure condition, the pressure vessel **10** will fail at the predetermined location **1410**.

(72) In another variant of the invention, as shown in **Figure 41**, the cellular reservoir flexible pressure vessel **10** has either a weakening or a spreading of fibers **1055** in either the upper **510** or lower **515** reinforcing panels at a predetermined location **1410**. The predetermined location **1410** is above the outer surface **536** of the pressure vessel **10**. When either of the upper **510** or lower **515** reinforcing panels has the fibers **1040** weakened or spread in the predetermined location **1410** and the pressure vessel **10** is subjected to an overpressure condition, the pressure vessel **10** will fail at the predetermined location **1410**.

(73) In an additional variant of the invention, as shown in **Figures 45 and 46**, the connection **88** to either a passageway **85** of another pressure vessel **10** or a valve **90** further has a capillary tube **1100**. The capillary tube **1100** has a proximate end **1105** and a distal end **1110** and is formed of resilient material **1115** and sized and shaped to fit slidably within the passageway **85**. High-strength braiding material is provided **295**. The braiding material **295**

is located about the capillary tube **1100** and extends along the capillary tube **1100** to within a first predetermined distance **1125** from the proximate end **1105**. The proximate end **1105** of the braiding **295** covered capillary tube **1100** is inserted into the passageway **85** and is either radio frequency welded or secured with adhesive to it. When the proximate end **1105** of the capillary tube **1100** is either welded or secured with adhesive within the passageway **85**, it will be permanently attached to it.

(74) In a further variant of the invention, as shown in **Figures 40 and 40A**, an apparatus **1130** for modifying flexible blanket material **1145** is provided. The apparatus **1130** has means **1135** for supporting a supply roll **1140** of flexible blanket material **1145**. Means **1150** for moving the flexible blanket material **1145** from the supply roll **1140** to a work area **1155** is provided. Means **1160** for tensioning the flexible blanket material **1145** in the work area **1155** is also provided. At least one separating member **1165** is provided. The separating member **1165** is sized and shaped to penetrate and separate fibers **1055** of the flexible blanket material **1145** is further provided.

Means **1175** for moving the separating member **1165** into the tensioned flexible blanket material **1145** at a predetermined location **1180** in the material **1145**, thereby either weakening and separating the fibers **1055** is provided. Means **1185** for retracting the separating member **1165** from the tensioned flexible blanket material **1145** is provided. Means **1190** for moving the flexible blanket material **1145** from the work area **1155** to a storage area **1195** is provided. The flexible blanket material **1145** will have either a weakened or separated fibers **1055** in the predetermined location **1180** prior to application to the pressure vessel **10**.

(75) In still a further variant of the invention, as shown in **Figures 40 and 40A**, an apparatus **1130** for modifying reinforcing panel material **1215** is provided. The apparatus **1130** has means **1135** for supporting a supply roll **1210** of reinforcing panel material **1215**. Means **1150** for moving the reinforcing panel material **1215** from the supply roll **1210** to a work area **1155** is provided. Means **1160** for tensioning the reinforcing panel material **1215** in the work area **1155** is provided. At least one separating member **1165** is provided. The separating member **1165** is sized and shaped to penetrate and separate fibers **1055** of the reinforcing panel material **1215**. Means **1175** for moving the separating member **1165** into the tensioned reinforcing panel material **1145** at a predetermined location **1180** in the material **1215**, thereby either weakening or separating the fibers **1055** is provided. Means **1185** for retracting the separating member **1165** from the tensioned reinforcing panel material **1215** is provided. Means **1190** for moving the reinforcing panel material **1215** from the work area **1155** to a storage area **1195** is provided. The reinforcing panel material **1215** will have either weakened or separated fibers **1055** in the predetermined location **1180** prior to application to the pressure vessel **10**.